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Content Analysis in Systems Engineering Acquisition Activities

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Panel 3. Systems Engineering: New Thinking for a New Age

Wednesday, May 4, 2016	
11:15 a.m. – 12:45 p.m.	**Chair: John D. Burrow,** Deputy Assistant Secretary of the Navy for Research, Development, Test, & Evaluation (DASN RDT&E) ***Rethinking the Systems Engineering Process in Light of Design Thinking*** Ronald Giachetti, Chair and Professor, NPS Clifford Whitcomb, Professor, NPS ***Content Analysis in Systems Engineering Acquisition Activities*** Karen Holness, Assistant Professor, NPS ***Update on the Department of the Navy Systems Engineering Career Competency Model*** Clifford Whitcomb, Systems Engineering Professor, NPS Corina White, Systems Engineering Research Associate, NPS Rabia Khan, Research Associate, NPS Dana Grambow, Research Psychologist, OPM Jessica Delgado, Technical Workforce Strategy Lead, DASN (RDT&E) José Vélez, Technical Workforce Lead, DASN (RDT&E)

Content Analysis in Systems Engineering Acquisition Activities

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Abstract

This paper examines the role of content analysis in systems engineering technical evaluation processes. Content analysis is a qualitative data analysis methodology used to discover consistencies, inconsistencies, themes, and trends within datasets. This methodology is particularly useful when evaluating Contract Data Requirements List documents, as well as deficiency reports from test and evaluation activities; examples of such analyses are provided. Factors that can impact a systems engineer's ability to effectively and efficiently use this analysis method are also discussed. Research into the development of valid, relevant, and repeatable analysis criteria promises to define (1) how content analysis can be used consistently across different system baselines and (2) how content analysis results generated during the "Production and Deployment" and the "Operations and Support" acquisition lifecycle phases can be used to shape requirements definitions for system upgrade or modification contracts and new baseline contracts. Finally, content analysis training and skill development for systems engineers in the acquisition workforce is discussed.

Introduction

During the different phases of a system's lifecycle, systems engineers evaluate a lot of data from a variety of sources. A key part of analyzing this data is discovering patterns and using those patterns to support additional analyses. As stated in the *International Council on Systems Engineering* (INCOSE) *Handbook,*

> Systems thinking captures and exploits what is common in a set of problems and corresponding solutions in the form of patterns of various types … Systems engineers use the general information provided by patterns to understand a specific system problem and to develop a specific system solution. (INCOSE, 2015)

A variety of quantitative and qualitative methods exist to (1) capture or generate data needed for a particular analysis, (2) reduce the data, (3) evaluate the data to find patterns, and (4) draw conclusions about the System Of Interest (SOI). This paper focuses on content analysis, a qualitative method that is well suited for datasets that contain primarily text-based data.

What Is Content Analysis?

Patton (2015) describes content analysis as "any qualitative data reduction and sense-making efforts that takes a volume of qualitative material and attempts to identify core consistencies and meanings. … The core meanings found through content analysis are patterns and themes." As defined by Krippendorff (2004), content analysis is used to make "replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use" and is most successful when evaluating attributions, social relationships, public behaviors and institutional realities. The basic steps to conducting a content analysis are summarized below. See either Krippendorff (2004) or Patton (2015) for detailed descriptions of each of these steps.

1. Decide what data sources to use for the analysis. These best fit the research questions (unitizing).
2. Identify a representative data subset to analyze (sampling).
3. Transform the raw data into analyzable data; evaluate and interpret characteristics within and between data elements by assigning elements to categories based on an observed pattern or theme. This can include inter-rater agreement studies for the categories (recording/coding).
4. Evaluate and interpret the categorized data, looking for additional patterns, themes, correlations (e.g., sub-categories) and outliers (reducing data).
5. Infer the meaning of the categories. Test and validate the inferences with respect to the research questions (inferring).
6. Summarize and communicate the analysis findings (narrating).

Content Analysis in Systems Engineering Activities

Within a systems engineering context, both “attributes” of system components and “institutional realities” with respect to operational and maintenance concepts for a given SOI are identified and evaluated during a system’s design lifecycle. Therefore, someone taking the time to gather existing text-based documents from either electronic or paper sources and look for patterns and themes is already done within systems engineering practice to varying degrees.

One example is the case where various stakeholders and/or representative users are interviewed to capture their inputs on what the SOI needs to do and what should be reflected in the corresponding system requirements and technical performance measures. The answers to the interview questions have to be evaluated and summarized in some fashion. Another example is performing trade studies, when various industry information sources are reviewed to understand the latest systems available on the market and current technology trends that may apply to the SOI. Reviewing different documents or websites, the systems engineer looks for very specific features and compares and contrasts them in some fashion. The INCOSE (2015) Systems Engineering Handbook describes, in detail, each of the standard technical processes and the various activities that take place within each process. Table 1 provides a sample of systems engineering activities described in the handbook that most likely involve the review of qualitative data from text-based sources.

Table 1. Sample of Systems Engineering Technical Process Activities for Content Analysis

(INCOSE, 2015)

Process	Activity
Business or Mission Analysis	• Analyzing gaps across the problem or opportunity trade space
Stakeholder Needs and Requirements Definition	• Eliciting and prioritizing stakeholder needs • Identifying solution constraints resulting from agreements or interfaces with other systems
System Requirements Definition	• Ensuring the system requirements adequately reflect the stakeholder requirements • Negotiating modifications to the requirements to resolve any issues identified
Architecture Definition Process	• Analyzing "relevant market, industry, stakeholder, organizational, business, operations, mission, legal, and other information" to guide architecture development
Design Definition	• Identifying types of design characteristics for each system element
Systems Analysis	• Comparing results from several types of models
Implementation	• Eliciting constraints related to implementation from "stakeholders, developers, and teammates" • Analyzing and resolving any anomalies that occurred during implementation
Integration, Verification and Validation	• Analyzing and resolving any anomalies that occurred during integration, verification and validation
Operations	• Identifying additional operations constraints and providing feedback to the system design team • Analyzing and resolving any anomalies that occur during operations
Maintenance	• Identifying additional maintenance constraints and providing feedback to the system design team • Analyzing and resolving any anomalies that occur during maintenance activities • Identifying trends in maintenance and logistics actions • Eliciting customer feedback on maintenance and logistics support process satisfaction

Of particular interest to this paper are the technical processes that take place after System Analysis. The Implementation, Integration, Verification and Validation processes typically span the "Engineering and Manufacturing Development" acquisition lifecycle phase. As described in Table 1, all of these processes share one activity in common: analyzing and resolving any anomalies that occur during each process's execution. During this phase, the product baseline for the SOI is reviewed and approved during the key Systems Engineering Technical Reviews (SETRs) that are required prior to the start of the "Production and Deployment" acquisition lifecycle phase: the Critical Design Review (CDR), Test Readiness Review (TRR), and the Production Readiness Review/Functional Configuration Audit (PRR/FCA).

In preparation for each of these SETR events, the contractor systems engineers evaluate the SOI's design and document its status in the required Contract Data Requirements List (CDRL) documents. Examples of these documents are Design Description documents, Product Drawings and Associated Lists (PDALs), and Deficiency or Discrepancy Reports (DRs). These documents are then reviewed and interpreted by the Government Systems Engineers, Logisticians, and Test & Evaluation (T&E) Engineers for accuracy and validity and in order to assess the SOI's adequacy and readiness. Any anomalies would be discussed with the contractors to either resolve or come up with a mitigation strategy, preferably before the SETR event.

While this may sound simple and straightforward, it can be a daunting task, even for systems with relatively few components and for documents housed in a configuration management software like DOORS®. Ensuring consistency within and across Design Description documents requires the system engineer to cross-reference the content of each document, looking for specific similarities and differences. This is important because each document focuses on detailed aspects of the same SOI. Similarly, the PDALs may contain hundreds of component and subsystem drawings, including those for the Commercial Off the Shelf (COTS) components. The contractor systems engineers have to review each component drawing, ensuring that the content makes sense and correlates with the other drawings that each one references. The interfaces depicted in these drawings must also match the same interfaces described in the design description documents. This matching task can reveal configuration errors that could impact component production in the next acquisition phase. For the DRs, it is the responsibility of the systems and T&E engineers to review these reports, evaluate them for patterns and themes, and interpret what those patterns and themes reveal about the performance of the software and hardware. The Government Systems Engineers, in an acquisition oversight role, independently repeat the same process for each one of these documents.

The systems engineer, as the Subject Matter Expert (SME), will be held accountable for the hardware and software's performance by the Program Manager. Looking for trends, correlations, and consistencies/inconsistencies helps the systems engineer evaluate the feasibility of the technical baseline and qualify the reliability and quality of the data used in the evaluation. For the Government Engineers, this kind of analysis also helps gauge the quality of the contractor's technical performance.

The Operations and Maintenance (O&M) processes described in Table 1 correspond to the "Production and Deployment" and the "Operations and Support" acquisition lifecycle phases. Like the previous technical processes discussed above, the O&M processes also analyze and resolve any anomalies that occur. Tracking system performance measures and periodically correlating that data to deficiency log data or maintenance action reports can reveal additional factors that are impacting system performance. Similar to the Implementation process, it is important that any additional constraints observed by users/operators, maintainers, other engineers or stakeholders within the O&M processes are captured, documented, and evaluated. Once fed back to the system designers, this information can then be used to shape requirements definition for system upgrade or modification contracts and new baseline contracts.

It is important to note that the systems engineers doing data analysis in the O&M processes may be different people than the ones who worked on the contract in previous phases of the acquisition lifecycle. Instead of working for the program office or the prime contractor, these systems engineers may work for the installation site and are responsible for capturing and analyzing system performance. Evaluating and packaging these data and data analysis results can be a different task if it is being done to support local management or will be provided to an outside organization for system design purposes.

Research on the Use of Content Analysis in Systems Engineering Activities

Systems engineers seem to be performing some level of content analysis. But, in which technical activities? How "well" is it being done? How valid are the results? Valuable insight can be gained by researching the actual use of content analysis in the technical processes previously discussed and what software tools are used and can be used to facilitate the process.

For example, Fortune and Valerdi (2013) developed a framework for determining how to reuse previously created engineering products for a new development effort. As part of the evaluation phase in this framework, the first step is to analyze both internally and externally developed products that are available, like requirements documents or modeling tools, then determine whether or not they apply to the SOI. Because this seems to involve a comparison of a previous system to the new SOI, an investigation into the effectiveness of using content analysis categories may prove to be useful. Since the next step in this framework is to estimate the costs and anticipated benefits from reusing the engineering products, having supporting evidence generated from a thorough content analysis may help to justify the investment.

It is easily hypothesized that the successful use of content analysis as a research methodology within a design environment or an operational setting would be impacted by factors such as

- Time required and resource availability to spend on the analysis
- Familiarity/Expertise with content analysis methods
- Familiarity/Expertise with the technical subject matter and data content
- Data access, particularly when data are spread across multiple print and electronic sources
- Data quality/quantity
- Individual personality—having the ability and patience to search for and identify patterns in datasets of various sizes

It would be worth researching the impact that content analysis would have on the system engineer's workload. Such a study could provide supporting evidence for hiring a dedicated data analyst on acquisition projects to perform various technical content analyses. Investigating the degree to which the other factors listed above actually impact content analyses can help identify constraints and possible mitigations to support the use of this methodology in different acquisition phases.

Another possible research path is the development of valid, relevant and repeatable analysis criteria that can be used across different system baselines. Granted, every system is unique. However, research to develop either (1) appropriate contexts and levels of depth for content analysis efforts within different acquisition phases or (2) generalizable categorizes for system attributes would help lay a foundation for integrating this methodology into the systems engineering toolkit. Having a common analysis tool that is easy to use would support the feedback of observed system performance trends from the operational and maintenance community to the design community, which would be used to develop requirements for system upgrade or modification contracts and new baseline contracts.

Finally, the implications of content analysis on training and skill development for systems engineers in the acquisition workforce should be investigated. Frank (2006) evaluated interview and survey data (using content analysis as part of his data analysis methodology) to characterize the cognitive characteristics and abilities of engineers with a high Capacity for Engineering Systems Thinking (CEST). While the ability to identify patterns and themes was not specifically identified in this study, the characteristic of understanding analogies and parallels between systems and the ability to conduct trade studies were identified. As an analysis methodology that specifically targets these abilities, it would be interesting to evaluate use of content analysis on the development or enhancement of these abilities. It would also be worth developing guidelines to use content analysis specifically in baseline comparison analyses, providing training on its use, then determining any impact to the perceived validity of the analysis results. Additional studies that test instructions on how to identify and validate data sources, gather data from these sources, and use commonly available software tools like Microsoft Excel would further demonstrate the feasibility of using this methodology.

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